

# Caries Management— Science and Clinical Practice

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Kim R. Ekstrand, Domenick T. Zero

# 1

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In simplified terms, dental caries develops because certain bacteria in the oral cavity ferment carbohydrates (sugars) into organic acids,<sup>1</sup> which in the case of lactic acid may result in dissolution of dental hard tissue.<sup>2</sup> However, in reality the etiology and pathogenesis of caries are much more complex and will be comprehensively discussed in the following chapters. All oral tissues, especially the dental hard tissues, microorganisms, and the saliva interact not only in the physiology of the oral cavity, but also in the caries process. Therefore it is important to know their composition, structure, and functions to understand the caries process.

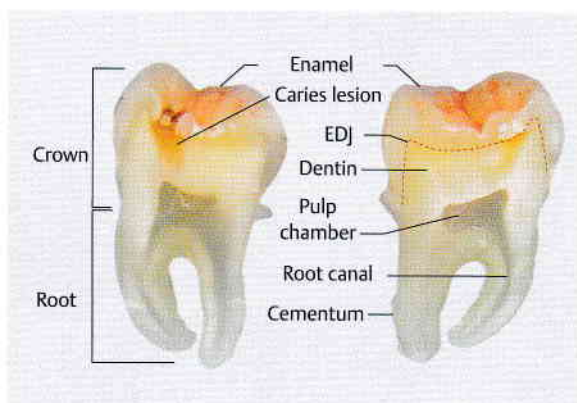
This chapter will deal with basic knowledge about the oral cavity focusing on the teeth, saliva, and oral microbiology, primarily from the perspective of caries disease. The subsequent chapters will build further on this knowledge. Age-related changes in dental hard tissue as well as in the salivary glands will also be touched on, as will related diseases and conditions other than caries.

In particular this chapter will cover:

- the structure of teeth,
- the functions of saliva,
- changes in the dental hard tissues and saliva with aging,
- dental plaque and its role in caries, and
- the interaction between tooth structure, saliva, and plaque in the oral cavity.

## Teeth

The structure of the coronal part of the teeth is as follows.<sup>3</sup> The **enamel** is the outermost layer covering the **dentin**, which in turn covers the **pulp** (Fig. 1.1). In the roots the outer layer consists of **cementum**, covering the dentin, which covers the pulp.



**Fig. 1.1** Hemi-sectioned molar showing the major components of the tooth. The dentin forms the bulk of the tooth and encloses the pulp chamber and root canals. The enamel covers the dentin in the coronal part of the tooth and the cementum covers the dentin in the roots. EDJ: enamel–dentin junction.

## Tooth Development and Tooth Emergence

Human beings have two sets of teeth: those belonging to the primary dentition, and those belonging to the permanent dentition. The conditions influencing the start of mineralization of the individual teeth, when the crowns are formed, the time for eruption, and when the roots are fully formed were mapped during the first half of the last century.<sup>4</sup> Teeth start to develop late in embryonic development. The first tooth type to erupt is most commonly a primary incisor in the lower jaw, which normally happens when the child is 6–8 months old (Fig. 1.2a). All teeth in the primary dentition are fully erupted when the child is about 2½ years old,<sup>6</sup> and approximal contact between first and second primary molars is seen about 1 year later.<sup>7</sup>

The first permanent teeth to erupt are either the central incisors or the first molar teeth; this happens in about 90% of children between 5 and 6 years of age.<sup>8</sup> The last permanent tooth to erupt is the third molar, which happens at the age of around 18 years. Thus, during a period of 18 years, different teeth erupt into the oral cavity, and between the ages of 5–6 and 12 years the child has a mixed dentition consisting of primary as well as permanent teeth (Fig. 1.2b).

## Macromorphological Terms

Professionals know where caries develops: in the primary dentition it develops mainly on the approximal and occlusal surfaces and occasionally on smooth surfaces along the gingival margin; in the permanent dentition it develops primarily on the occlusal surfaces, foramen cecum, and later, on approximal surfaces. In the elderly, caries also develops on root surfaces. The following paragraph will describe macromorphological terms related to these caries-prone sites of the teeth.

## Occlusal Surfaces

In a simple model, Carlsen (1987) suggested dividing the crowns of teeth into **lobes**—from one (e.g., incisors) to five (e.g., some molars) in number.<sup>3</sup> Often molar teeth have five lobes, each with an essential cusp. Three of them (Fig. 1.3a) are the facial lobes, namely the mesiofacial, centrofacial, and distofacial lobes, which are separated on the occlusal surface by the mesiofacial and distofacial interlobal grooves. These interlobal grooves run down to the facial surface. In particular, the mesiofacial interlobal groove can end cervically in a (sometimes deep) tract called the **foramen cecum**.

The remaining two lobes are placed lingually: the mesiolingual and distolingual lobes separated on the occlusal surface by the lingual interlobal groove. The facial lobes are separated from the lingual lobes by the mesial and distal interlobal grooves. Where the interlobal grooves meet, a tract called the **fossa** arises. Thus molar teeth often have at least three fossae: the mesial, central, and distal

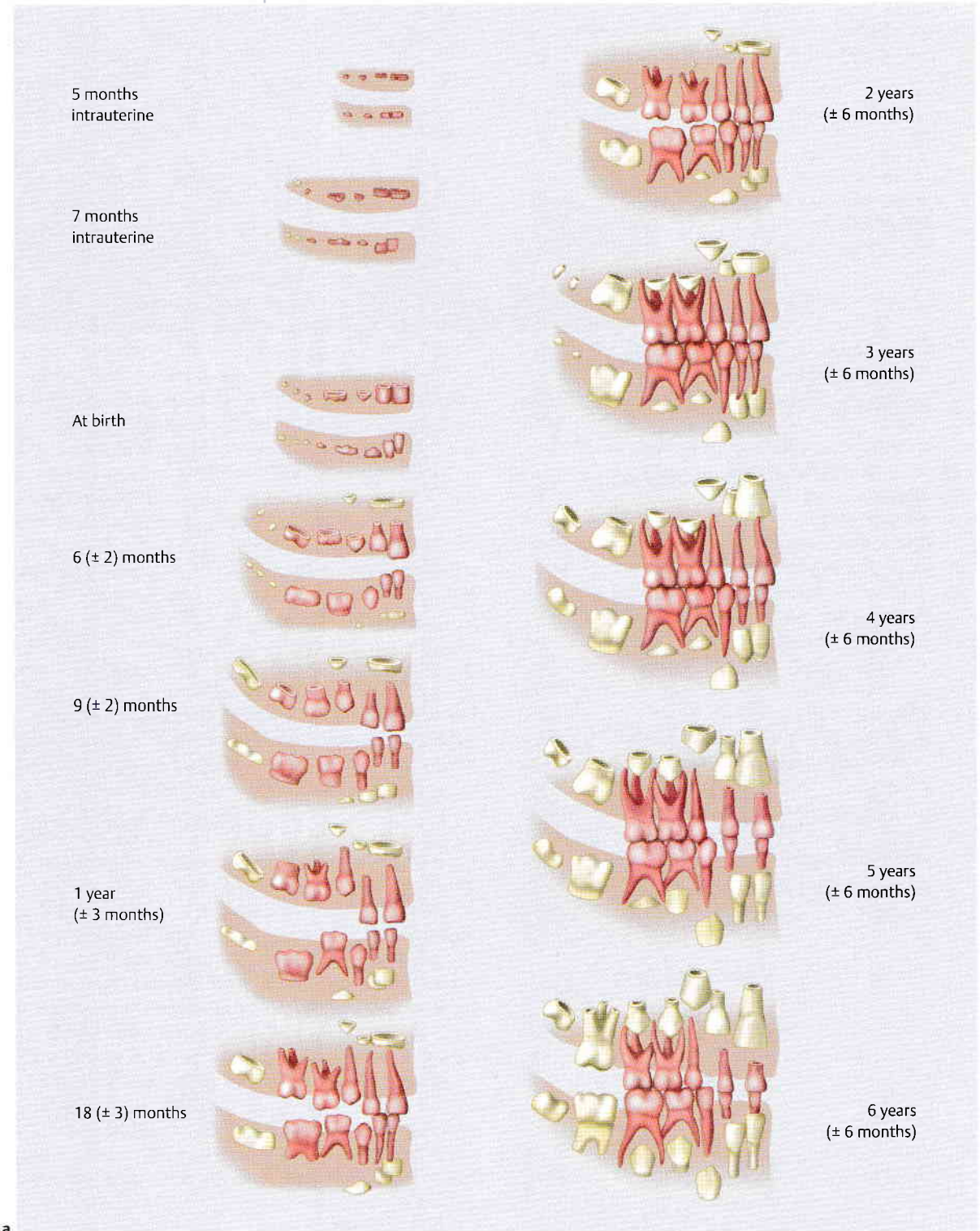
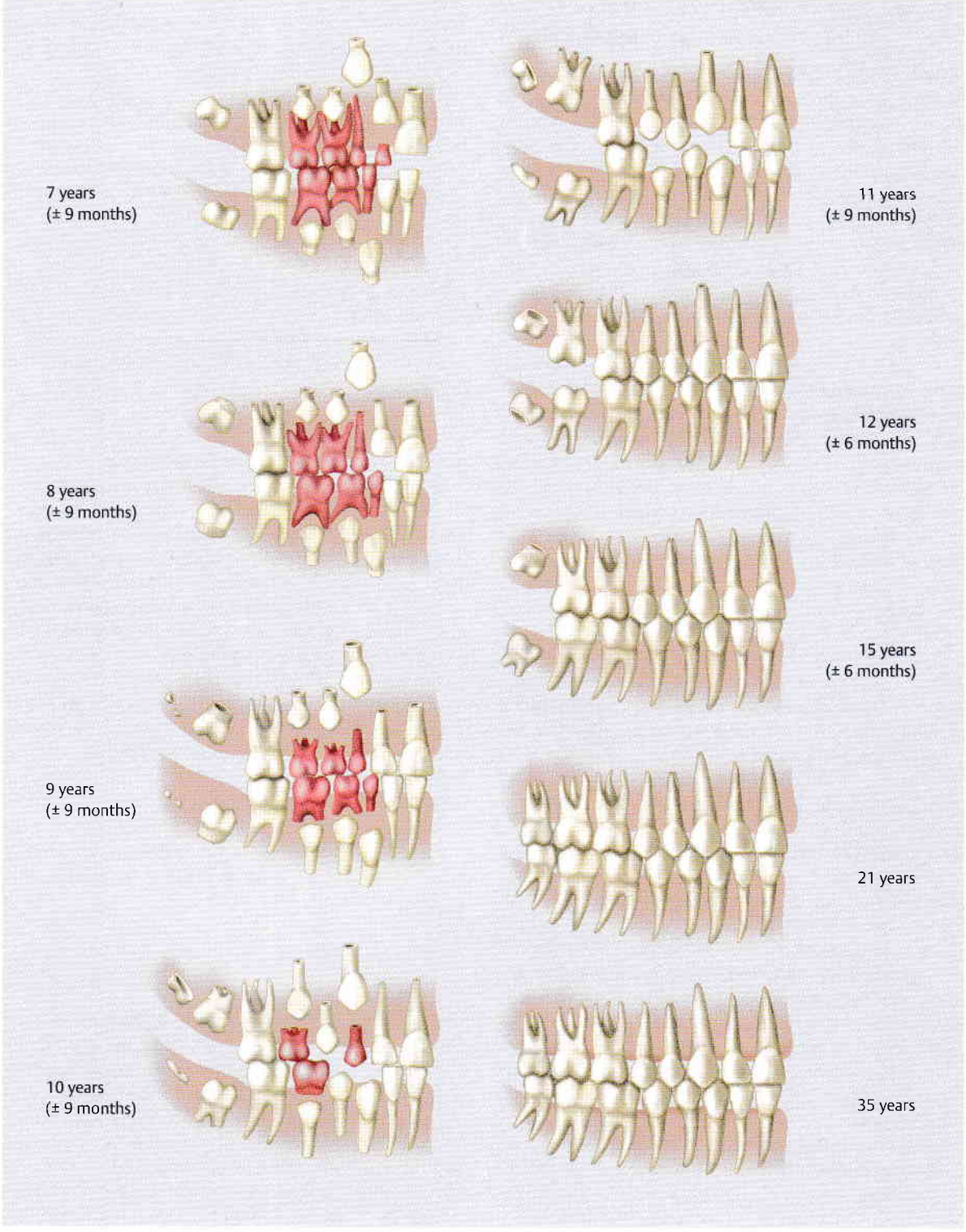


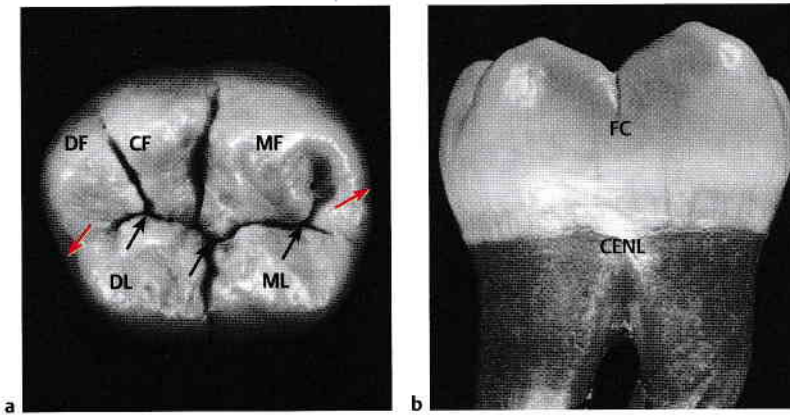
Fig. 1.2a,b Development and growth patterns of the teeth in both dentitions.<sup>5</sup>

Fig. 1.2b >



b

Fig. 1.2 (Continued)

**Fig. 1.3a,b**

- a** Occlusal aspect of a permanent first molar. MF, CF, and DF are the mesiofacial, centrofacial, and distofacial lobes. The ML and DL are the mesiolingual and distolingual lobes. Black arrows point to fossae areas and red arrows point to margino-segmental grooves.
- b** Lingual aspect of a first permanent molar. The cervical enamel line/cemento-enamel junction separates the crown from the root. FC: location of foramen cecum.

fossae (Fig. 1.3a). On each lobe there are also several **intersegmental grooves**. On the marginal ridge, particularly in molars, grooves termed **margino-segmental grooves** run downward along the approximal surface. Premolars have normally two lobes, one buccal and one lingual, separated by the mesiodistal interlobal groove.

The total number of grooves, intersegmental grooves, and fossae on the occlusal surface are termed the “**groove–fossa system**,” replacing the classical term “**pits and fissure system**.” To build a bridge between the two classification systems, it has been suggested that the groove–fossa systems can be fissurelike or groove-like, where “fissurelike” is defined as an area where the bottom of the groove–fossa system is not clinically visible. On the occlusal surface, caries most often develops in wide fissures and in the fossae areas.<sup>9</sup>

## Approximal Surfaces

On approximal surfaces at least three macromorphological features can influence the development of caries and must be taken into consideration:

- The width and location of the approximal contact area. That is, approximal surfaces on tooth types with narrow contact points (front teeth) have less caries than approximal surfaces of tooth types with wide approximal surface contact areas (molar teeth).<sup>10,11</sup>
- The curvature of the approximal surfaces. Certain molars in both dentitions show a degree of concavity on the approximal surfaces.<sup>3</sup>
- The margino-segmental grooves (Fig. 1.3a) may contribute to an uneven contact with the adjacent tooth, and the grooves can be both fissurelike and groove-like.

## The Cervical Enamel Line and the Roots

The cervical enamel line (Fig. 1.3b) is also termed the cemento-enamel junction and is the boundary line between the anatomical crown and the anatomical root complex.<sup>3</sup> In patients with healthy gingiva, the line/junction is at the same level as the marginal gingiva. This line/junction is irregular and rough, so microorganisms can adhere easily to this area of the tooth.

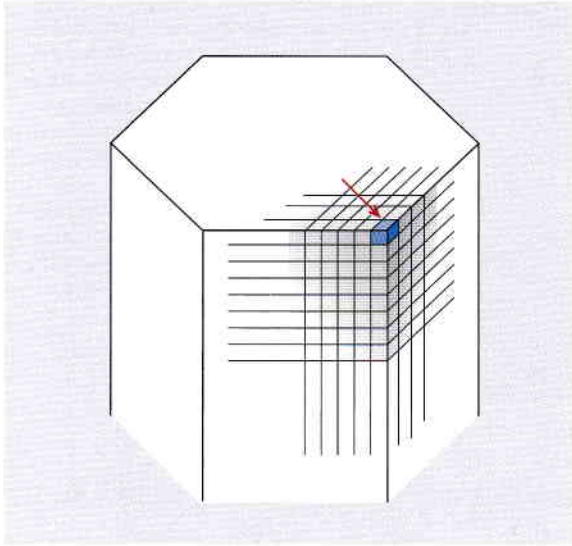
Apart from some grooves on the roots of particular teeth, there are no macromorphological structures which promote caries development in the roots. Rather, the gingiva around the neck of the tooth promotes stagnation of microorganisms, eventually developing into plaque. In the case of gingival recession, new plaque stagnation areas are formed where root caries can develop.

### NOTE

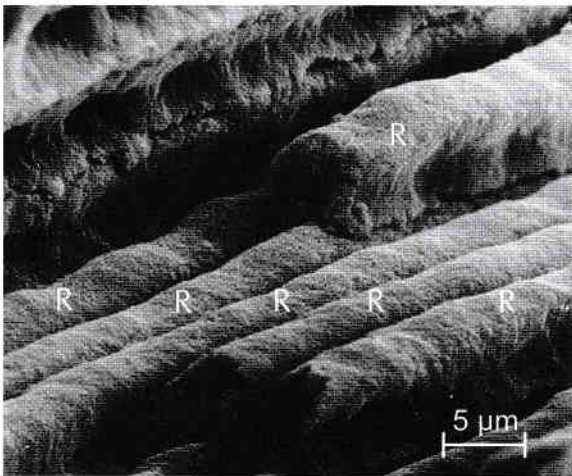
Caries usually develops in specific locations in the teeth: these are the occlusal surfaces, the approximal surfaces, and along the gingival margin.

## Enamel

The enamel is formed by **ameloblasts** in three consecutive steps. Initially, the ameloblasts secrete proteins in such a way that the final form of the tooth is developed; simultaneously, a part of the protein is replaced by mineral. This is the **secretory phase** of amelogenesis.<sup>12</sup> The majority of the protein is, however, replaced by mineral during the **maturation stage** of amelogenesis, which takes place over several years. The amelogenesis ends at the time for emergence of the tooth when the reduced ameloblast fuses with the epithelium cells. More details can be found in Mjör and Fejerskov.<sup>12</sup>



**Fig. 1.4** Illustration showing the structure of a hydroxyapatite crystal. The smallest repeating entity of the crystal in enamel (arrow) has in its purest form the formula  $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$ .



**Fig. 1.5** Scanning electron microscopic images of enamel rods (R) built up by crystals.

## Chemical Composition and Structure of Apatite Crystals

The inorganic content of mature enamel amounts to 96%–97% by weight; the remainder is organic material and water. On the basis of volume around 86% is mineral, 12% is water, and 2% is organic material.<sup>12</sup>

Owing to its hardness, enamel is difficult to cut for histological examinations used to study its structure. Therefore different approaches have been considered to describe its nature. One way to do this is at the crystalline level. In material science, a crystal is a solid substance in which the atoms, molecules, or ions are arranged in an orderly repeating pattern extending in all three dimensions. The crystals made by the ameloblasts consist of

calcium phosphate, and the smallest repeating entity of the crystals in enamel has, in its purest form, the formula  $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$ , which is termed **hydroxyapatite** (HAP) (**Fig. 1.4**). The crystals are approximately hexagonal in cross-section, with a diameter of ca. 40nm. The length of the crystals is difficult to assess, but today it is assumed that the length is between 100nm and 1000nm.<sup>13</sup>

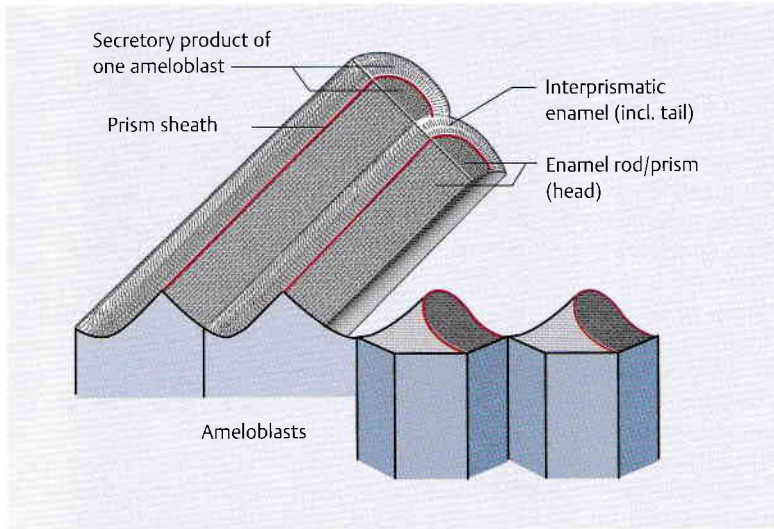
At the chemical level, several substitutions of the ions in HAP can and do occur (resulting in impure forms of HAP)—for example, substitution with fluoride giving **fluoride hydroxyapatite** (FHAP); with carbonate, **carbonate-modified hydroxyapatite** (CHAP); and with magnesium, **magnesium-modified hydroxyapatite** (MHAP). **Fluorapatite** is a crystal where (nearly) all of the  $\text{OH}^-$  ions in HAP are replaced by fluoride, and which has a lower solubility than HAP; this, however, is not that common in human enamel.<sup>14</sup> More commonly, the  $\text{OH}^-$  ions are only partially replaced by fluoride, and FHAP is formed. These crystals also have a lower solubility than HAP, which again has lower solubility than CHAP.<sup>15–17</sup> These chemical conditions have great influence on the caries process and will be highlighted in Chapters 2 and 3.

The individual crystals are arranged in rods (or prisms) (**Fig. 1.5**) extending from the enamel–dentin junction to the surface, with an average diameter of about 4–5 $\mu\text{m}$ . The crystals in the rods all align in the same direction except at the periphery, where the crystals change direction from those in the core of the rod. Thus, the space between the crystals or intercrystalline spaces (also called the pore volume which is filled with air, water, or proteins) is larger at the periphery of the rod than at the core. As the periphery of one rod meets other peripheries of other rods, the pore volume between rods is relatively large and much larger than in the core of the rod (**Fig. 1.6**). This is important for caries formation as acid and other products more easily penetrate through areas of enlarged pore volume (see also Chapter 3).

Due to this uniform structure of the enamel with tightly packed crystals, **light** penetrates through the enamel and is reflected or absorbed in the dentin. Well mineralized, permanent enamel is translucent, and it is the underlying dentin which, eventually, gives the tooth its color (**Fig. 1.7**). If the **pore volume** in the enamel increases, the light is scattered and reflected in the enamel which results in a white color. Primary teeth (see **Fig. 1.7**), which show a greater pore volume than the erupting permanent enamel, appear therefore whiter than permanent teeth.

Macroscopically/clinically the enamel generally looks smooth and even (**Figs. 1.3, 1.7**); however, at high magnification the surface enamel is full of **developmental defects** such as pits, cracks, and fissures<sup>18,19</sup> as well as normal anatomical features such as Tomes' process pits corresponding to the head of the ameloblasts (**Fig. 1.8**). Thus, there are numbers of surface irregularities on enamel where the microorganism can shelter.

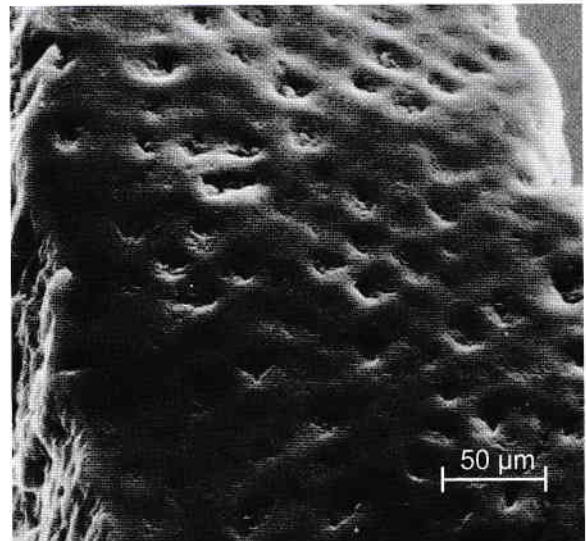
In some parts of the surface enamel, and particularly in teeth of the primary dentition, the enamel is covered by crystals which are not organized as rods, but the direc-



**Fig. 1.6** Schematic illustration of three-dimensional arrangement of enamel crystallites within the rods (prisms) resulting from their formation by ameloblasts. Note the in the prism periphery, the crystal orientation changes abruptly, resulting in enlarged intercrystalline spaces in the prism boundaries.<sup>45</sup>



**Fig. 1.7** Mandibular front teeth of a 6-year-old child, with erupting permanent first incisors. They appear more yellowish than the adjacent more opaque deciduous teeth, owing to the color of the underlining dentin. \* protuberances.



**Fig. 1.8** Scanning electron microscopic view of an enamel surface showing developmental defects as Tome's process pits, large enough for microorganisms to shelter in them.

tions of the individual crystals are oriented perpendicular to the surface. This layer is called aprismatic enamel<sup>12</sup> and can present problems when etching enamel for sealing/bonding procedures (see below).

**NOTE**

Enamel is the hardest tissue in the human body; however, it is still soluble in acid with a pH below 5.5. The inorganic content of enamel is hydroxyapatite (HAP), fluoride hydroxyapatite (FHAP), carbonate-modified hydroxyapatite (CHAP), and magnesium-modified hydroxyapatite (MHAP). FHAP is less soluble than HAP, which is less soluble than CHAP or MHAP.

**The Dentin–Pulp Organ**

The dentin and the pulp (see Fig. 1.1) are closely related developmentally and functionally. The odontoblasts, which are the cells responsible for the formation of the dentin, are separated from the pulp cells only by a cell-free zone.

In contrast to the enamel, dentin continues to be formed after crown formation is complete. This is called secondary dentin formation, which over time results in reduction of the size of the pulp chamber.

The dentin consists of about 70 wt% inorganic material, 18 wt% organic material, and 12 wt% water.<sup>12</sup> As in the enamel, the inorganic material consists of HAP crystals (20nm in length, <20nm in width, and 3.5nm in thick-